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A PRECISION AUXANOMETER

W. T. BOVIE

(WITH TWO FIGURES)

In the auxanometers which have been described up to the present time, a thread or string has been used to transmit the motion of the growing plant to the recording device. This construction is always faulty, because changes in humidity affect the length of the thread, and so falsify the record. The author has designed a machine which eliminates the thread and its unavoidable errors by substituting for it material which is not affected by humidity and which is very little altered by changes in temperature.

On account of the error due to the thread, it has heretofore been impracticable to use a recording device which would indicate small increments in length. On account of the great precision of the new instrument such a device is needed, and accordingly the recording mechanism has been refined until it is capable of registering an increment of a single micron.

It has hitherto been necessary, except with the auxanometer described by FROST,[1] to place the recording device in close proximity to the plant. This is cumbersome and has prevented the simultaneous recording of the growth of a number of plants. FROST'S machine used a thread, but as the growth was recorded electrically, simultaneous records of the growth of several plants could be made. This valuable feature has been incorporated in the new auxanometer.

The machine consists essentially of a device which is carried upward as the plant grows. When this device has moved a certain small distance, it closes an electric circuit which operates the recording pen of a chronograph. As the connection of the plant with the circuit-closing device is made with invar, a metal with an exceedingly small coefficient of expansion with changes of temperature, the growth can be accurately measured to a very few microns, and by using a condenser in the electric circuit, as described later, the growth can be recorded to a single micron.

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[1] Minnesota Botanical Studies no. 17. 1894.

The mechanism may be understood by referring to fig. 1. The plant is attached by the invar wire *a* to the small spring *b*, which pulls upward a little more than is necessary to lift the weight of the wire (the exact amount of this pull may be regulated easily by a screw not shown in the drawing). Experiment has shown that this slight pull is not enough to affect the growth of the plant.

As the spring moves upward, it comes in contact with the block *c* at the point *c′*. This closes the electric circuit, which up to this time has been open, since the spring *b* is insulated from *c* at its other point of contact. The current which now flows through the line energizes the coil *d*, which draws the escapement lever upward. The block *c* is carried on the screw *f*, which is connected by a train of wheels at *f′* to a clock spring, which tends to turn the screw in such a manner as to raise the block *c* upward. The screw is prevented from turning by the escapement lever *e*, but when the escapement lever is drawn up by the magnet *d*, it allows the screw to turn a given part of a revolution. The block *c* is therefore raised a certain distance and the circuit opened. The plant must now grow exactly this distance before the circuit is closed again.

The upward movement of the block *c* is determined by the pitch of the thread of the screw *f* and the amount it turns. By changing the number of teeth in the escapement wheel at the top of the screw *f*, the amount it turns at each contact can be controlled. There are 20 teeth in the escapement wheel, and so the screw can be made to turn 1/20 of a revolution, or if part of the teeth are removed, it will turn more, up to a complete revolution. If the pitch of the screw is 0.5 mm., each record represents 25μ.

It may be noted, in passing, that the micrometer screw has become the standard device for measuring small distances. It is not the purpose of this account to give the mechanical specifications of the apparatus; there are many ways in which the various details can be constructed. It may be said, however, that the screw should be straight and accurate. (The screw from a phonograph, with its nut, is an excellent and inexpensive micrometer.) It should turn easily and run true in its bearings, and the nut in the block *c* should be so constructed as not to bind. In this machine use is made of a split nut which is tightened by a conical cap into which it fits.

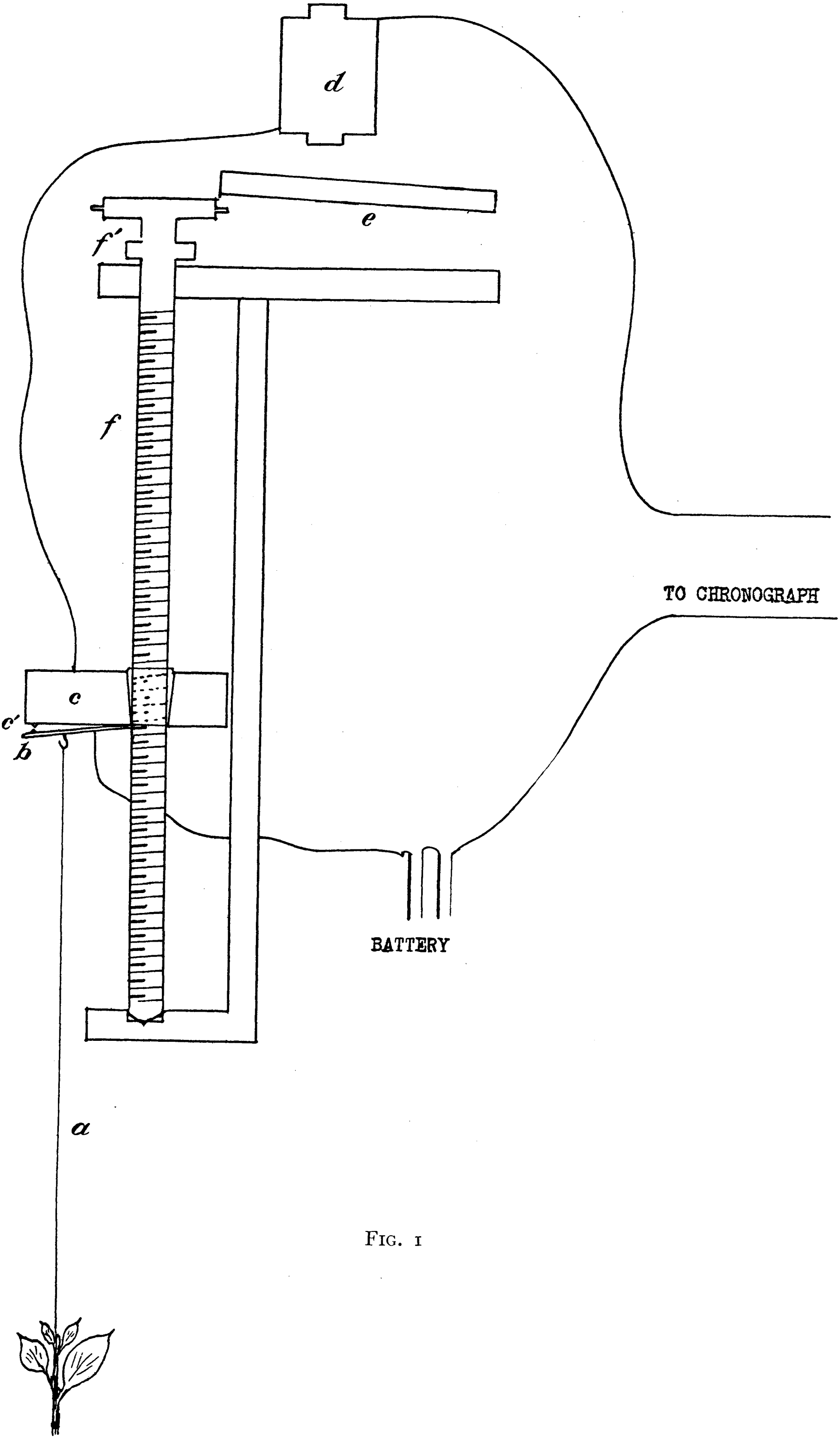

FIG. 1

The escapement should be such that one (and only one) tooth of the escapement wheel can pass at one closing of the circuit. This becomes important when the screw has to make a complete revolution for each record.

The chronograph was constructed especially for this apparatus. The drum turns once in six hours, and is of such a diameter that 1 mm. on the drum corresponds to one minute in time. The drum is long enough to receive the records from six auxanometers at one time, and holds one week's record. The pens are stationary, the drum turning under them and moving forward in the line of its own axis, so that each pen traces a spiral on the record sheet. At each closing of the circuit the pen makes a check in the line traced. When the record is removed for reading, we have a series of parallel lines, each representing six hours of time. By counting the number of checks in a given length of time, or by measuring the distance between the checks, the rate of growth can be determined.

By means of a small switchboard, an electric bell or an electric light can be included in the circuit, so that each time an increment of growth is recorded the light flashes and the bell rings. This is used only for lecture experiments. A tungsten lamp should be employed, as the length of contact is so short that an Edison lamp does not have time to become luminous.

An elongating hyacinth peduncle, which had been in the damp greenhouse and was removed to the dry air of the lecture-room, gave a record a little oftener than once a minute. Had the plant been left in the greenhouse and only the chronograph taken to the lecture-room, the contacts would have been more frequent. A young sunflower seedling gave a record every 18 seconds. Such records are too frequent for experiments of long duration, as there are too many checks to count. When working with plants growing at this rate, some of the teeth in the escapement wheel should be removed.

The principle of having the plant automatically close and open an electric circuit during growth permits the increase in length to be measured to almost any degree of accuracy. The only difficulty is a tendency to arcing across the spark gap between the spring *b* and the block *c*. There are two ways of preventing this: the wire *a* may be attached near the fixed end of the spring *b*, thus making the gap longer than the distance recorded, or a condenser (such as is used in a telephone for instance) may be placed around the gap. The latter method will also tend to prevent burning of the terminals. Terminals of platinum and gold give the best results. Even with these precautions there will be a limit to the accuracy of a single record, for the two metal surfaces will not always give electrical contact at the same place. But as any experiment includes a great number of records, these slight errors will average up so that the results will be absolutely accurate.

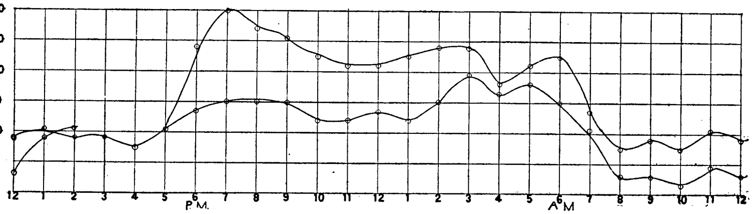

FIG. 2.—Curve of rate of growth of the hypocotyl of a four-o'clock seedling; abscissas indicate time, ordinates growth per hour in microns; total time recorded, 46 hours; total growth recorded, 1.75 cm.

Time	1	2	3	4	5	6	7	8	9	10	11	12
Checks per hour	..	..	..	5	7	16	20	18	17	15	14	14
	15	16	16	12	14	15	9	5	6	5	7	6
	7	6	6	5	7	9	10	10	10	8	8	9
	8	10	13	11	12	10	7	2	2	1	3	2
	6	7	..	..	..	..	..	..	..	..	..	..

A record is given in fig. 2 of a four-o'clock seedling for the first 46 hours after it appeared above the ground. The making of this record put the machine to an extreme test, as these seedlings are very delicate. It will be noted that the curve is very even, and that it passes very close to the points from which it is plotted. The relation of the rate of growth to light is clearly shown. The records were made in January, when the laboratory darkened early. The temperature of the laboratory falls considerably at night, getting coldest at 4 o'clock in the morning, at which time the day fireman starts up the fires. It will be noted that on both nights the rate of growth changes sharply at this point. The first internode did not elongate as much on the second day as it did on the first, hence the curve for this day is everywhere below the first one. Very interesting curves can be produced when several plants are compared, or when the increments of the various internodes of the same plant are recorded simultaneously.

The writer is now working in cooperation with the L. E. Knott Apparatus Company on a new model, which involves a different mechanism for opening the circuit. This machine will be smaller, and it is hoped that it can be put on the market at a very low cost.

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